A Flexible Microassembly Cell for Small and Medium Sized Batches

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ABSTRACT

The reason why microsystems are not economically profitable is that assembly is very expensive, if done in small or medium sized batches. We will show that a Flexible Microassembly Cell will allow to assemble small and medium sized batches in an economical way. This cell is based on a high precision robot with an integrated graphic interface that enables the operator to perform step-by-step assembly operations and at the same time saves the parameters used for each action of the process. At a later stage the assembly process can be repeated automatically in a faster way for the remaining microsystems. We will describe the design and operation of the Flexible Microassembly Cell with an example: the assembly of watch plates.

Keywords Microassembly, flexible assembly, precision robot, man-machine interface, micro-assembly workshop, remote-operation

1 THE MICROSYSTEM ASSEMBLY PROBLEMATIC

At present, only a few microsystems are produced in large quantities. In such cases the production tools, including the assembly line, are fully dedicated to the task and the automation level is very high. Since microsystem based products comprise many functions their applications are very specific, which explains why production batches are mainly small or medium sized [Zühlke 97]. In many occasions those products can't succeed in the market because of the high cost of assembly.

Microsystem assembly encounters problems of different nature: feasibility, component handling, required precision and component quality [Reinhart 97].

The required positioning precision is roughly of 1-5 µm, which is more or less the limit of human capability. Such precision can be attained by an operator a couple of times with the aid of a microscope but there is no chance the operator will be able to perform the task over and over again in a production line. In addition due to the reduced size of the parts (at least one of the functional dimensions is smaller 1 mm.) inertia forces (weight) are smaller than surface forces (surface tension effect, electrostatic forces, etc.), which makes handling with tweezers or other tools very tedious since parts have the tendency to stick to them [Benmayor 00], [Arai 96].

Precision equipment is required to successfully carry out assembly operations, usually robots that work within the field of view of a camera [Reinhart 00], [Allegro 98]. Automation is necessary not only for economic reasons, as is the case in conventional assembly, but also to guarantee the required precision and repeatability. Such equipment is complex and expensive and it should be possible to make it profitable with small and medium sized production batches. To achieve this goal the same equipment should be flexible enough to be used for the assembly of different microsystems [Koelemeijer et al. 99], [Koelemeijer 01].

An added difficulty in microassembly that can't be neglected is the poor quality of the system components. The variation of the functional dimensions due to manufacturing processes that are difficult to control don't allow to keep tolerances within the desired limits, especially when prototypes or a pilot production are being assembled.

2 WHICH FLEXIBILITY FOR MICROSYSTEMS ASSEMBLY ?

Although a high precision, flexible microassembly station capable of handling small and medium size production lots economically is badly needed, it is not available in the market.

But, what do we mean exactly by flexibility?

Firstly, the assembly cell must assemble medium sized batches of a few thousand units as well as small series of a few tens of thousands. At the same time it must be capable of working with a few prototypes built from the few components available, because of the low yield. The size of the batches to assemble range from a few units to several thousands.

Secondly the investment on equipment is important. Dead times between different production series, when changing product, introducing a new one or when passing from a few units to a several thousands batch, should be avoided or reduced to the strict minimum.

Finally the equipment must be able to handle the parts despite the variability of their dimensions.

To achieve the required level of flexibility it is necessary to take advantage of both the human and the machine's qualities. The strong points of a robot are its repeatability, the execution of precise and controlled movements, and the possibility to fit it with measuring systems (displacement meters, vision systems, etc.). On the other hand among its weakest points we find that it can only perform the tasks it has been built or programmed for, it does not take decisions on what should be done. Among the human qualities emphasize its ability to auto-organise itself, to take multi-dimensional decisions, to judge ill-defined situations and to react to unexpected events.

The quality of the components poses a big problem when prototype microsystems are assembled because the number of functional components on a wafer is frequently very low.

The "intuitive programming" interface that we are developing takes into consideration the advantages of the operator and the machine. The interface allows to use the robot in semi-automatic mode or to program the different assembly stations of a microassembly workshop.

3 MICROASSEMBLY WORKSHOP

3.1 Workshop structure

As we conceive it, a micro-assembly workshop (Figure 1) comprises several assembly stations with different axis resolutions, each equipped with different functions (pick&place, glue module, etc.). It is committed to the assembly and packaging of micro-system based products in small lots (prototypes), or medium sized lots (pilot production lots). The workshop at the Laboratoire de Production Microtechnique at the EPFL includes:

- A micro-assembly cell based on a 4 degrees of freedom robot with a resolution of 5 µm.
- A micro-assembly cell based on a 4+2+3 degrees of freedom robot with a resolution of 0,5 µm.
- A "Global Scene" Cell used to learn the position of the components on the pallets.
- A wire-bonder.

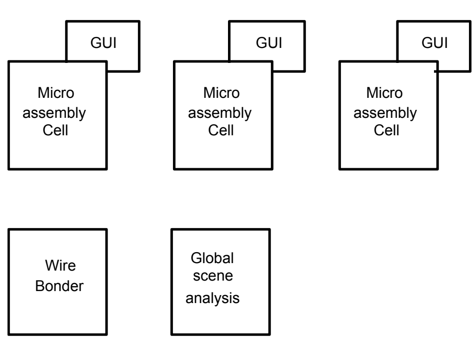

Figure 1 – Structure of a microassembly workshop.

3.2 Working pallets

The workshop is structured in job-shop mode. The transfer of parts or sub-assemblies in batches on pallets is done by an operator. Since the assembly cells have a large autonomy, the number of transfers between cells is low. An automated transfer would not be advantageous from the flexibility point of view (the itinerary of the pallets will vary from product to product) nor from the economic standpoint [Koelemeijer et al. 02].

The working pallet is divided into different sectors that hold smaller, nested pallets that carry the components that have to be assembled or the assembled products (Figure 2).

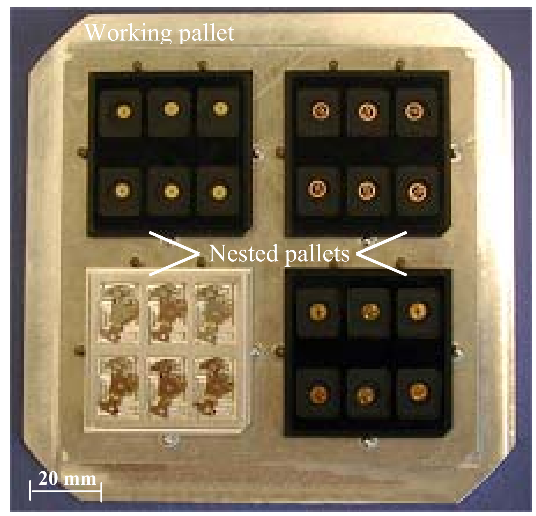

Figure 2 – Working pallet with nested pallets.

3.3 « Global Scene » Cell

The Global Scene Cell is used to define the position of the different elements and components on a working pallet. With this global information the assembly cell can locate and manipulate any component within that pallet (Figure 2). This cell is made up of an area where the working pallet is placed and a camera linked to the assembly cells (Figure 3).

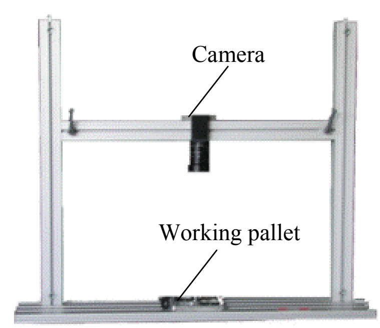

Figure 3 – Global scene cell

The field of view of the camera covers the whole pallet, which can't be done with the cameras on the assembly cells due to resolution restrictions. The image and information obtained are used in the assembly cell graphic interface and by the robot to plan its trajectories. It is also possible to teach the robot the position of the nests on a pallet or the location of the calibration points.

3.4 The Flexible Microassembly Cells

The robots and equipment:

Our two Flexible Microassembly Cells are based on robots manufactured by Sysmelec.

The first cell is based on a 4 degrees of freedom robot with a resolution of 5 µm and a working volume of approximately 150x150x150 mm^3. A vision system with a camera placed next to the gripper is integrated to the robot.

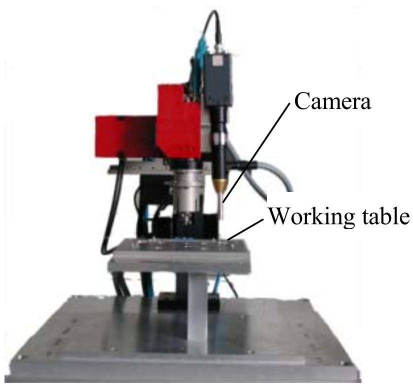

Figure 4 - Robot 4 axes and 5 µm resolution

The second assembly cell is based on a 4 degrees of freedom robot (x-y-z-θ) with a resolution of 0,5 µm. A vision system with camera and numerically controlled zoom and focus lens is integrated into the Z-axis of the robot (2 dof). This configuration keeps the robot's gripper within the field of view of the camera at all times, making it possible to control the relative position of gripper and component with the feedback of the vision system. The working volume is roughly the same as the first cell. A second 3 degrees of freedom robot is in charge of dispensing the glue. In the near future a wafer feeder will be added to this cell so components can be picked directly from the wafers and there will be no need to palletise them [Koelemeijer et al. 02].

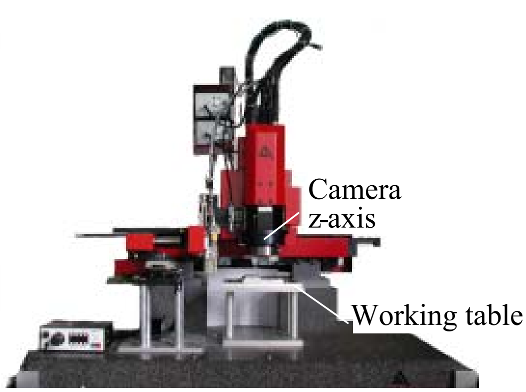

Figure 5 – Robot 6 axes 0.5 µm resolution

Both assembly cells can be equipped with interchangeable grippers. Both assembly cells can perform the following assembly tasks with the limitations imposed by their characteristics:

- Detection and measurement of component position in the x, y and z directions as well as in rotation.
- Component gripping.
- Detection and measurement of the position where the component has to be placed.
- Component placement.
- Dispensing and distributing glue in every desired pattern.
- Packaging of assembled micro-system.

Structure of the Flexible Microassembly Cell

A requirement for an assembly cell to be flexible enough to handle small and medium sized production lots is that it is possible to add or modify the cell's functions or calculation routines. It is therefore important to have a flexible software structure that allows to make the required modifications in a simple and fast way. The diagram below shows the structure we have chosen for our cells, keeping in mind the flexibility required.

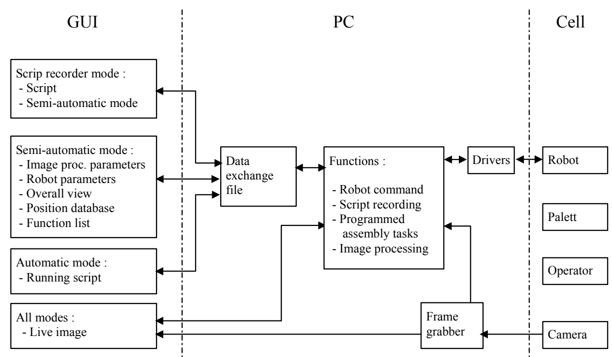

Figure 6 – Cell structure

3.5 Operating modes of the Flexible Microassembly Cell

The Flexible Microassembly Cell can work in three different modes:

Semi-automatic Mode or tele-operation

In the semi-automatic mode the operator makes the robot perform the tasks of the assembly procedure one by one according to the assembly plan. Those tasks are generically pre-programmed and the operator has to simply define the parameters for the present operation: pick and place positions to be analysed by the vision system, the pick and place positions to be used, etc. This mode is used to assemble very small lots as well as components that aren't repetitive enough for automatic assembly. The operator controls the robot by means of a graphic interface (GUI) (Figure 7), which comprises 6 windows:

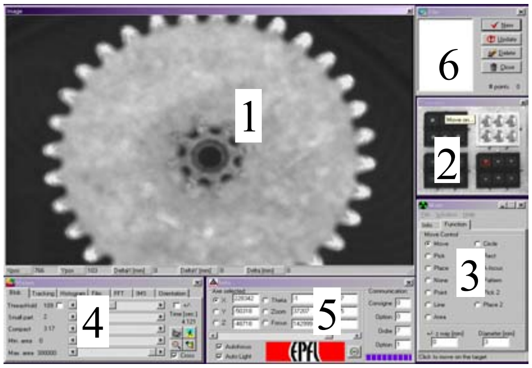

Figure 7 – GUI overview

1. A window with the image of the camera mounted on the robot. This is the main window.
2. A window with the image of the working pallet, used for rough positioning of the gripper.
3. A window where the different pre-programmed tasks can be selected (Move, Pick, Place, etc).
4. A window where the different functions or settings of the vision system can be selected or adjusted.
5. A window with a table that controls the position and speed of all axes, lenses and lighting systems.
6. A database containing the memorized positions received from the Global Scene Cell.

The operator chooses the point where he wants to place the robot by clicking on the image of the working pallet (Window 2). The robot moves to the requested position and is now within the field of view of the camera. The operator can define the point with a higher degree of precision in the enlarged image of Window 1. He can also use the pre-programmed image processing functions of the vision system such as the determination of the center of gravity of a part to locate the best position, etc.

The operator defines the task to be performed on Window 3 (pick a part, move the robot, deliver glue, etc.). Next he clicks on the application point on the image of Window 1, which corresponds to what the robot is ”seeing”. The robot performs the task and stands by till the next task is ordered.

« Script Recorder » or Intuitive Programming Mode

As in the semi-automatic mode, the operator executes the generic functions in the correct order introducing the required parameters. Additionally the operator must tell the robot the number of pieces that have to be assembled, the location of all the components and the assembly sequence. With all this information the system will generate the assembly program for the robots. The operator has works with the same tools as the ones found in semi-automatic mode and in addition has a script-recording window. Before each task is performed the operator sets the parameters in the same way, as he would do in semi-automatic mode. In the script-recording window the operator highlights a command line and associates it to a specific task such as pick a part, move, etc. Each script line includes a task and the parameters related to it: point-locating method, image processing parameters, etc. The completed script can be tested step by step and saved for immediate or later use.

Automatic Mode

In automatic mode the operator loads the cell with a working pallet and the assembly of the components takes place automatically. The operator can see on the screen what the robot is seeing during the assembly operations, the global scene of the working pallet and a window that controls the automatic mode. This last window includes parameters such as the number of pallets to use, the number of pallets already assembled, a RUN button, a PAUSE button, an indicator of the program status and an activity log.

3.6 Application

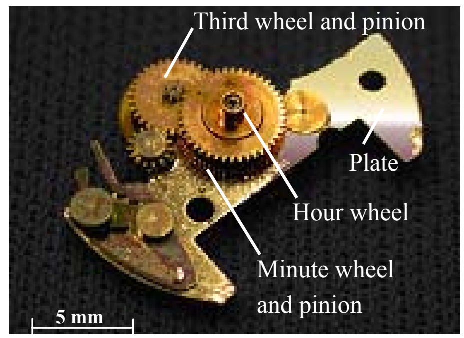

Figure 8 – The assembly of watch plates

The example we are using has no industrial interest. We will show how to carry out the assembly of a watch plate in semi-automatic mode using the high-resolution assembly cell (0,5 µm). The time required to perform the different operations have been measured so the reader can get a realistic view of how easy and fast it is to program the assembly cell.

Assembly Sequence

The watch plates, which are partially assembled and lodged in the nests of the pallet, will receive new components.

The following elements are mounted on the plate:

- The minute module (comprises the minute wheel and pinion)
- Third wheel and pinion
- Hour wheel

Detailed list of tasks:

- Pick the minute module.
- Position the minute module above the center axis (placing point).
- Insertion of the minute module in the center axis.
- Pick the third wheel.
- Position the third wheel above the third axis (placing point).

- Insertion of the third wheel in the third axis.
- Pick the hour wheel.
- Position the hour wheel above the center axis (placing point).
- Insertion of the hour wheel in the center axis.

Work preparation

The first thing the operator has to do is prepare the job for the assembly cell and configure it for the assembly of the watch plate. Those operations can be carried out in masked time. Be aware that operations 3 and 5 are only necessary to start up with a new batch.

1. Manual fill-in of the different components in the nested pallets.
   Duration: 60[s]
2. Placement of the nested pallets on the working pallet.
   Duration: 10[s]
3. Data acquisition on the "Global Scene" cell and transfer to assembly cell.
   Duration: 20[s]
4. Placement of the working pallet on the cell's working table.
   Duration: 10[s]
5. Calibration of the overall image and reference to the cell's coordinate system.
   Duration: 50[s]
6. Back up of defined parameters for future use.
   Duration: 10[s]

The assembly cell is ready for production in less than 3 minutes. The semi-automatic assembly of a watch plate can now begin:

Assembly in semi-automatic mode:

- The operator moves the robot's camera and places it over the minute module by clicking on the corresponding zone on the overall image of the working pallet (or selecting the name of the point if it has been saved previously).
  Duration: 1[s]
- To determine precisely the center of the minute module the operator selects the necessary image processing functions (threshold setting and computation of center of gravity). Z-axis displacement is also calculated from zoom and depth-from-focus [Allegro 98].
  Duration: 0,5[s]
- The task "pick" is selected before clicking on the center of the module as defined by the image processing system. The robot moves to the selected point and picks the minute module.
  Duration: 3[s]
- The operator moves the robot to the placing point, which in this case is the center axis of the plate, by clicking on the appropriate zone on the overall image of the pallet.
  Duration: 1[s]
- As before the operator selects the appropriate image processing functions to determine precisely the position of the axis (threshold setting and computation of center of gravity). Z-axis displacement is also calculated from zoom and depth-from-focus.
  Duration: 0,5[s]
- The operator selects the "place" function and clicks on the axis center defined by the vision system. The robot places the module in its final location.
  Duration: 3[s]

The total assembly time for the minute module is of 9 seconds.

The same procedure is used to assemble the remaining wheels, pinions and plates. Once the working pallet is finished, the operator can replace it with a fresh one and continue the assembly of the remaining plates.

The recording of a script to perform the same assembly job automatically is very similar. Each action performed by the robot has to be recorded in the appropriate order.

4 RELEVANT TIMES

The set up of the assembly cell for a semi-automatic or automatic assembly job is less than 3 minutes. But only 90 seconds are necessary to refeed the next pallet.

The semi-automatic assembly of a wheel takes 9 seconds, and that of the whole plate about 30 seconds. We have 6 plates on a working pallet, so it cost 3 minutes to assemble them all. Feeding needs less time and therefore can be performed in masked time in automatic mode.

The set up of the robot to work in automatic mode can be done in a very short time. Although this function has not been completely implemented we estimate the set up time to be less than 5 minutes.

The set up time for a product that was already assembled in the past is negligible, and of only a few minutes to set up an assembly procedure for a new product.

5 CONCLUSION AND FUTURE WORK

Our concept of Flexible Micro-Assembly Cell and intuitive programming is particularly well adapted to the assembly of small lots because the programming time is extremely short. The only condition is that we must be able to assemble the product using the existing functions on the cell.

Our present and future work will be focused on developing the script recorder and implementing new generic assembly functions.

We are also developing interchangeable grippers to be able to manipulate components of different shapes and sizes. In addition we are working on the integration of new handling modules on the assembly cells as for example a wafer feeder with a device to pick the components directly from the wafer.

6 ACKNOWLEDGMENT

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